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## PATENT APPLICATION

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VIRTUAL REALITY NETWORK

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PATENT

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VIRTUAL REALITY NETWORK

## BACKGROUND OF THE INVENTION

This invention relates to computer systems and, more particularly, to a network wherein multiple users may share, perceive, and manipulate a virtual environment generated by a computer system.

Researchers have been working with virtual reality systems for some time. In a typical virtual reality system, people are immersed in three-dimensional, computer-generated worlds wherein they control the computer-generated world by using parts of their body, such as their hands, in a natural manner. Examples of virtual reality systems may be found in telerobotics, virtual control panels, architectural simulation, and scientific visualization. See, for example, Sutherland, W.R., "The Ultimate Display", Proceedings of the IPIP Congress 2, 506-508 (1965); Fisher, S.S., McGreevy, M., Humphries, J., and Robbinett, W., "Virtual Environment Display System," Proc. 86 Workshop 3D Graphics, 77-87 (1986); F.P. Brooks, "Walkthrough - A Dynamic Graphics System for Simulating Virtual Buildings", Proc. 1986 Workshop on Interactive 3D Graphics, 9-25 12 (1986); and Chung, J.C., "Exploring Virtual Worlds with Head-Mounted Displays", Proc. SPIE Vol. 1083, Los Angeles, CA, (1989). All of the foregoing publications are incorporated herein by reference.

In known systems, not necessarily in the prior art, a user wears a special helmet that contains two small television screens, one for each eye, so that the image appears to be three dimensional. This effectively immerses the user in a simulated scene. A sensor mounted on the helmet keeps track of the position and orientation of the user's head. As the user's head turns, the computerized scene shifts accordingly. To interact with objects in the simulated world, the user wears an instrumented glove having sensors that detect how the hand is bending. A separate sensor, similar to the one on the helmet,

determines the hand's position in space. A computer-drawn image of a hand appears in the computerized scene, allowing the user to guide the hand to objects in the simulation. The virtual hand emulates the movements of the real hand, so the 5 virtual hand may be used to grasp and pick up virtual objects and manipulate them according to gestures of the real hand. An example of a system wherein the gestures of a part of the body of the physical user is used to create a cursor which emulates the part of the body for manipulating virtual objects is 10 disclosed in copending U.S. Patent Application Serial No. 317,107, <sup>now U.S. Patent No. 4,986,981 issued January 29, 1991,</sup> filed February 28, 1989, <sup>A</sup> entitled, "Computer Data Entry Manipulation Apparatus and Method," incorporated herein by reference.

To date, known virtual reality systems accommodate 15 only a single user within the perceived virtual space. As a result, they cannot accommodate volitional virtual interaction between multiple users.

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#### SUMMARY OF THE INVENTION

The present invention is directed to a virtual reality network which allows multiple participants to share, perceive, and manipulate a common virtual or imaginary environment. In one embodiment of the present invention, a computer model of a virtual environment is continuously 20 modified by input from various participants. The virtual environment is displayed to the participants using sensory displays such as head-mounted visual and auditory displays which travel with the wearer and track the position and orientation of the wearer's head in space. Participants can 25 look at each other within the virtual environment and see virtual body images of the other participants in a manner similar to the way that people in a physical environment see each other. Each participant can also look at his or her own virtual body in exactly the same manner that a person in a 30 physical environment can look at his or her own real body. The participants may work on a common task together and view the 35 results of each other's actions.

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## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagram of a particular embodiment of a virtual reality network according to the present invention;

5 Fig. 2 is a diagram of a data flow network for coupling real world data to a virtual environment.

Fig. 3 is a diagram showing three participants of a virtual reality experience;

10 Fig. 4 is a diagram showing a virtual environment as perceived by one of the participants shown in Fig. 2;

Fig. 5 is a diagram showing an alternative embodiment of a virtual environment as perceived by one of the participants shown in Fig. 2; and

15 Fig. 6 is a flowchart showing the operation of a particular embodiment of a virtual reality network according to the present invention.

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## BRIEF DESCRIPTION OF THE APPENDICES

App. 1 is a computer program listing for the virtual environment creation module shown in Fig. 1;

20 App. 2 is a computer program listing for the Data coupling module shown in Fig. 1; and

App. 3 is a computer program listing for the visual display module shown in Fig. 1.

## 25 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Fig. 1 is a diagram showing a particular embodiment of a virtual reality network 10 according to the present invention. In this embodiment, a first participant 14 and a second participant 18 share and experience the virtual environment created by virtual reality network 10. First participant 14 wears a head-mounted display 22(A) which projects the virtual environment as a series of image frames much like a television set. Whether or not the helmet completely occludes the view of the real world depends on the desired effect. For example, the virtual environment could be superimposed upon a real-world image obtained by cameras located in close proximity to the eyes. Head-mounted display 22(A) may comprise an EyePhone (TM) display available from VPL

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Research, Inc. of Redwood City, CA. An electromagnetic source 26 communicates electromagnetic signals to an electromagnetic sensor 30(A) disposed on the head (or head-mounted display) of first participant 14. Electromagnetic source 26 and 5 electromagnetic sensor 30(A) track the position of first participant 14 relative to a reference point defined by the position of electromagnetic source 26. Electromagnetic source 26 and electromagnetic sensor 30(A) may comprise a Polhemus Isotrak (TM) available from Polhemus Systems, Inc. Head-mounted display 22(A), electromagnetic source 26, and 10 electromagnetic sensor 30(A) are coupled to a head-mounted hardware control unit 34 through a display bus 38(A), a source bus 42(A), and a sensor bus 46(A), respectively.

First participant 14 also wears an instrumented glove 15 assembly 50(A) which includes an electromagnetic sensor 54 for receiving signals from an electromagnetic source 58. Instrumented glove assembly 50(A), electromagnetic sensor 54(A) and electromagnetic source 58 are used to sense the position and orientation of instrumented glove 50 relative to a 20 reference point defined by the location of electromagnetic source 58. In this embodiment, instrumented glove assembly 50(A), electromagnetic sensor 54(A) and electromagnetic source 58 are constructed in accordance with the teachings of co-pending patent application no. 317,107 entitled "Computer Data 25 Entry And Manipulation Apparatus And Method." More particularly, instrumented glove assembly 50(A), electromagnetic sensor 54(A) and electromagnetic source 58 may comprise a DataGlove (TM) available from VPL Research, Inc. Instrumented glove assembly 50(A), electromagnetic sensor 30 54(A), and electromagnetic source 58 are coupled to a body sensing control unit 62 through a glove bus 66, a sensor bus 70, and a source bus 74, respectively.

Although only an instrumented glove assembly is shown in Fig. 1, it should be understood that the position and 35 orientation of any and all parts of the body of the user may be sensed. Thus, instrumented glove 50 may be replaced by a full body sensing suit such as the DataSuit (TM), also available from VPL Research, Inc., or any other body sensing device.

In the same manner, second participant 18 wears a head-mounted display 22(b) and an electromagnetic sensor 30(b) which are coupled to head-mounted hardware control unit 34 through a display bus 38(b) and a sensor bus 46(b), 5 respectively. Second participant 18 also wears an instrumented glove assembly 50(b) and an electromagnetic sensor 54(b) which are coupled to body sensing control unit 62 through a glove bus 66(b) and a sensor bus 70(b).

In this embodiment, there is only one head-mounted hardware control unit 34, body sensing control unit 62, electromagnetic source 26, and electromagnetic source 58 for both participants. However, each participant may be located separately from each other, in which case each participant would have his or her own head-mounted hardware control unit 15 34, body sensing control unit 62, electromagnetic source 26, and/or electromagnetic sensor 58.

The position and orientation information received by head-mounted control unit 34 are communicated to a virtual environment data processor 74 over a head-mounted data bus 76. 20 Similarly, the position and orientation information received by body sensing control unit 62 are communicated to virtual environment data processor 74 over a body sensing data bus 80. Virtual environment data processor 74 creates the virtual environment and superimposes or integrates the data from head-mounted hardware control unit 34 and body sensing control unit 25 62 onto that environment.

Virtual environment data processor 74 includes a processor 82 and a virtual environment creation module 84 for creating the virtual environment including the virtual 30 participants and/or objects to be displayed to first participant 14 and/or second participant 18. Virtual environment creation module 84 creates a virtual environment file 88 which contains the data necessary to model the environment. In this embodiment, virtual environment creation 35 module 84 is a software module such as RB2SWIVEL (TM), available from VPL Research, Inc. and included in app. 1.

A data coupling module 92 receives the virtual environment data and causes the virtual environment to

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dynamically change in accordance with the data received from head-mounted hardware control unit 34 and body sensing control unit 62. That is, the virtual participants and/or objects are represented as cursors within a database which emulate the 5 position, orientation, and other actions of the real participants and/or objects. The data from the various sensors preferably are referenced to a common point in the virtual environment (although that need not be the case). In this embodiment, data coupling module 92 is a software module such 10 as BODY ELECTRIC (TM), available from VPL Research, Inc. and included in app. 2. Fig. 2 shows an example of a simple data flow network for coupling data from the head of a person in the real world to their virtual head. Complex interactions such as hit testing, grabbing, and kinematics are implemented in a 15 similar way. The data flow network shown in Fig. 2 may be displayed on a computer screen and any parameter edited while the virtual world is being simulated. Changes made are immediately incorporated into the dynamics of the virtual world. Thus, the participants are given immediate feedback 20 about the world interactions he or she is developing. *C2*

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The animated virtual environment is displayed to first participant 14 and second participant 18 using a virtual environment display processor 88. In this embodiment, virtual environment display processor 88 comprises one or more left eye 25 display processors 92, one or more right eye display processors 96, and a virtual display module 100. In this embodiment, each head-mounted display 22(a), 22(b) has two display screens, one for each eye. Each left eye display processor 92 therefore 30 controls the left eye display for a selected head mounted display, and each right eye display processor 96 controls the right eye display for a selected head mounted display. Thus, each head mounted display has two processors associated with it. The image (viewpoint) presented to each eye is slightly different so as to closely approximate the virtual environment 35 as it would be seen by real eyes. Thus, the head mounted displays 22(A) and 22(B) produce stereophonic images. Each set of processors 92, 96 may comprise one or more IRIS(TM) processors available from Silicon Graphics, Inc.

5 The animated visual environment is displayed by a series of image frames presented to each display screen within head-mounted displays 22(a) and 22(b). These frames are computed by a visual display module 100 which runs on each processor 92, 96. In this embodiment, visual display module 108 comprises a software module such as ISAAC (TM), available from VPL Research, Inc. and included in app. 3.

10 In this embodiment, only the changed values within each image frame are communicated from processor 82 to left eye display processors 92 and right eye display processors 96 over an Ethernet bus 108. After the frames for each eye are computed, a synchronization signal is supplied to processor 82 over a hard-sync bus 104. This informs processor 82 that the next image frame is to be calculated, and processor 82 then 15 communicates the changed values needed to calculate the next frame. Meanwhile, the completed image frames are communicated to head-mounted hardware control unit 34 over a video bus 112 so that the image data may be communicated to head-mounted displays 22(a) and 22(b).

20 Fig. 3 is a diagram of virtual reality network 10 as used by three participants 120, 124 and 128, and Figs. 3 and 4 provide examples of the virtual environment as presented to two of the participants. As shown in Figs. 3-5, participants 120 and 124 engage in a common activity whereas participant 128 25 merely watches or supervises the activity. In this example, and as shown in Figs. 4 and 5, the activity engaged in is an engineering task on a virtual machine 132 wherein virtual machine 132 is manipulated in accordance with the corresponding gestures of participants 120 and 124. Fig. 4 shows the virtual 30 environment as displayed to participant 120. Of course, the other participants will see the virtual environment from their own viewpoints or optical axes. In this embodiment, the actions of the participants shown in Fig. 3 are converted into corresponding actions of animated participants 120(A), 124(A) 35 and 128(A), and the virtual environment is created to closely match the real environment.

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A unique aspect of the present invention is that the appearance and reactions of the virtual environment and virtual

participants are entirely within the control of the user. As shown in Fig. 5, the virtual environment and actions of the virtual participants need not correspond exactly to the real environment and actions of the real participants. Furthermore, 5 the virtual participants need not be shown as humanoid structures. One or more of the virtual participants may be depicted as a machine, article of manufacture, animal, or some other entity of interest. In the same manner, virtual machine 132 may be specified as any structure of interest and need not 10 be a structure that is ordinarily perceivable by a human being. For example, structure 132 could be replaced with giant molecules which behave according to the laws of physics so that the participants may gain information on how the molecular world operates in practice.

15 It should also be noted that the real participants need not be human beings. By using suitable hardware in processor 82, such as the MacADIOS (TM) card available from GW Instruments, Inc. of Summerville, Mass., any real-world data may be modeled within the virtual environment. For example, 20 the input data for the virtual environment may consist of temperature and pressure values which may be used to control virtual meters displayed within the virtual environment. Signals from a tachometer may be used to control the speed of a virtual assembly line which is being viewed by the 25 participants.

Viewpoints (or optical axes) may be altered as desired. For example, participant 128 could share the viewpoint of participant 120 (and hence view his or her own actions), and the viewpoint could be taken from any node or 30 perspective (e.g., from virtual participant 120(A)'s knee, from atop virtual machine 132, or from any point within the virtual environment).

Fig. 6 is a flowchart illustrating the operation of a particular embodiment of virtual reality network 10. The 35 virtual environment is created in a step 200, and then nodes on the virtual objects within the virtual environment are defined in a step 204. The raw data from head-mounted hardware control unit 34 and body sensing control unit 62 are converted to

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position and orientation values in a step 208, and the position and orientation data is associated with (or coupled to) the nodes defined in step 204 in a step 212. Once this is done, processors 92 and 96(a) may display the virtual objects (or participants) in the positions indicated by the data. To do this, the viewpoint for each participant is computed in a step 216. The system then waits for a synchronization signal in a step 218 to ensure that all data necessary to compute the image frames are available. Once the synchronization signal is received, the image frame for each eye for each participant is calculated in a step 220. After the image frames are calculated, they are displayed to each participant in a step 224. It is then ascertained in a step 228 whether any of the nodes defined within the virtual environment has undergone a position change since the last image frame was calculated. If not, then the same image frame is displayed in step 224. If there has been a position change by at least one node in the virtual environment, then the changed position values are obtained from processor 82 in a step 232. It is then ascertained in a step 234 whether the virtual environment has been modified (e.g., by changing the data network shown in Fig. 2). If so, then the virtual object nodes are redefined in a step 236. The system again waits for a synchronization signal in step 218 to prevent data overrun (since the position and orientation values usually are constantly changing), and to ensure that the views presented to each eye represent the same information. The new image frames for each eye are then calculated in a step 220, and the updated image frames are displayed to the participants in a step 224.)<sup>C3</sup>

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30 While the above is a complete description of a preferred embodiment of the present invention, various modifications and uses may be employed. For example, the entire person need not be simulated in the virtual environment. For the example shown in Fig. 1, the virtual environment may 35 depict only the head and hands of the virtual participant. Users can communicate at a distance using the shared environment as a means of communications. Any number of users may participate. Communications may take the form of speech or

other auditory feedback including sound effects and music; gestural communication including various codified or impromptu sign languages; formal graphic communications, including charts, graphs and their three-dimensional equivalents; or 5 manipulation of the virtual environment itself. For example, a window location in the virtual reality could be moved to communicate an architectural idea. Alternatively, a virtual tool could be used to alter a virtual object, such as a virtual chisel being used to chip away at a stone block or create a 10 virtual sculpture.

A virtual reality network allows the pooling of resources for creation and improvement of the virtual reality. Data may be shared, such as a shared anatomical data base accessible by medical professionals and students at various 15 locations. Researchers at different centers then could contribute then different anatomical data to the model, and various sites could contribute physical resources to the model (e.g., audio resources, etc.).

Participants in the expressive arts may use the 20 virtual reality network to practice theatrical or other performing arts. The virtual reality network may provide interactive group virtual game environments to support team and competitive games as well as role playing games. A virtual classroom may be established so that remotely located students 25 could experience a network training environment.

The virtual reality network also may be used for real time animation, or to eliminate the effects of disabilities by the participants. Participants with varying abilities may interact, work, play and create using individualized input and 30 sensory display devices which give them equal abilities in the virtual environment.

Stereophonic, three-dimensional sounds may be presented to the user using first and second audio displays to produce the experience that the source of the sound is located 35 in a specific location in the environment (e.g., from the mouth of a virtual participant), and three-dimensional images may be presented to the participants.

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Linking technology for remotely located participants include Ethernet, phoneline, broadband (ISDN), and satellite broadcast, among others. Data compression algorithms may be used for achieving communications over low bandwidth media. If 5 broadband systems are used, a central processor may process all image data and send the actual image frames to each participant. Prerecorded or simulated behavior may be superimposed on the model together with the real time behavior. The input data also may come from stored data bases or be 10 algorithmically derived. For example, a virtual environment could be created with various laws of physics such as gravitational and inertial forces so that virtual objects move faster or slower or deform in response to a stimulus. Such a virtual environment could be used to teach a participant how to 15 juggle, for example.

Other user input devices may include eye tracking input devices, camera-based or others input devices for sensing the position and orientation of the real world participants without using clothing-based sensors, force feedback devices as 20 disclosed in U.S. Patent Application No. 315,252 entitled "Tactile Feedback Mechanism For A Data Processing System" filed on February 21, 1989 and incorporated herein by reference, ultrasonic tracking devices, infrared tracking devices, magnetic tracking devices, voice recognition devices, video 25 tracking devices, keyboards and other conventional data entry devices, pneumatic (sip and puff) input devices, facial expression sensors (conductive ink, strain gauges, fiber optic sensors, etc.), and specific telemetry related to the specific environment being simulated, i.e., temperature, heart rate, 30 blood pressure, radiation, etc. Consequently, the scope of the invention should not be limited except as described in the claims.

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